Complex Adaptive Systems and Interactive Granular Computing

Andrzej Skowron[1,2(✉)]

[1] Institute of Mathematics, Warsaw University, Banacha 2, 02-097 Warsaw, Poland
skowron@mimuw.edu.pl

[2] Systems Research Institute, Polish Academy of Sciences,
Newelska 6, 01-447 Warsaw, Poland

Extended Abstract. We discuss an approach to modeling of computations performed by Complex Adaptive Systems (CAS) based on Interactive Granular Computing (IGrC).

Complex adaptive systems (CAS) are made up of multiple interacting elements and have the capacity to change and learn from experience. The key problems of complex systems are difficulties with their formal modeling and simulation[1]. Some approaches to modeling CAS are based on agent-based models and/or complex network-based models (see, *e.g.*, [17,36]).

Decision support in solving problems related to CAS [6,33,36] requires relevant computation models for the agents as well as methods for incorporating reasoning over computations performed by agents. Agents are performing computations on complex objects (*e.g.*, behavioral patterns, classifiers, clusters, structural objects, sets of rules, aggregation operations, approximate reasoning schemes). In Granular Computing (GrC), all such constructed and/or induced objects are called granules.

To model, crucial for CAS, interactive computations [2] performed by agents, we extend the existing GrC approach to Interactive Granular Computing (IGrC) by introducing *complex granules* (*c-granules* or *granules*, for short).

Interactive granular computations (*computations in* IGrC, for short) were proposed as computational models for complex systems. Reasoning about the properties of computations in IGrC are based on *adaptive judgment*.

Computations in this model are performed on c-granules thanks to which it is possible to register, analyze, and synthesize the properties of interactions between physical objects perceived by agents.

We assume that the states of certain physical objects, occurring within a specific domain of activity of a given c-granule, are directly measurable. However, the states of other objects are perceived (approximated) indirectly using measurable states, obtained by interactions of physical objects from a particular domain of c-granule's activity. Each measurable state of a c-granule (at a given moment

[1] https://en.wikipedia.org/wiki/Complex_adaptive_system.

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of the agent's time) corresponds to a concept. This concept is understood as a set of situations (configurations of physical objects), perceived within this very c-granule, and, thanks to interactions, leads to a specific state. In the proposed approach, the concept of a measurable state means that such states are represented by, *e.g.*, the values of a corresponding attribute or by the *satisfiability degrees* of corresponding to states concepts/formulas. Following the aggregation of c-granules, more complex c-granules, corresponding to structural objects, their properties, or relations over measurable states (*e.g.*, *preference relations*), can be represented by c-granules. C-granules are used by agents for perceiving current situations or states and undertaking, on this basis, of relevant actions.

The fundamental intuition behind the concept of a c-granule is the following: the control of an agent *ag* uses her/his c-granules for perceiving and/or accessing fragments of the surrounding physical world. Each c-granule consists of three architectural layers:

1. *Soft_suit*, *i.e.*, configurations of hunks which represent the properties of the *ag*'s environment of activity (including the properties of the present, past, and expected phenomena, as well as expected properties of interaction plans and/or the results of some interactions, potentially activated by a c-granule).
2. *Link_suit*, *i.e.*, communication channels (links) which transmit the results of interactions among accessible fragments of the agent's environment of activities and the results of interactions among different representations of properties in the soft_suit; according to the weight (significance) of the current *ag*'s needs, links may have assigned priorities, which reflect the results of judgment, performed by *ag*.
3. *Hard_suit*, *i.e.*, configurations of hunks accessible by links from the link_suit.

The hard_suits, link_suits, and soft_suits of more compound c-granules are defined using the relevant networks over already defined c-granules. The networks are satisfying some constraints which can be interpreted as definitions of types of networks. The link_suits of such more compound granules are responsible for transmission of interactions between the hard_suits and soft_suits represented by the corresponding networks. The results and/or properties of transmitted interactions are recorded in the soft_suits.

Any c-granule is making it possible to record in its soft_suit the perceived by it interactions in its hard_suit which are transmitted by the link_suit to the soft_suit. This is typical for sensory measurement. On the other hand, a c-granule may cause some interactions in its hard_suit by transmitting through its link_suit some interactions from the soft_suit. However, the c-granule may perceive the results (or properties) of such caused in the hard_suit interactions only by using the soft_suit. This is done on the basis of the transmitted results (or properties) of these caused interactions in the hard_suit by transmitting them back through the link_suit to the soft_suit. These results (or properties) may be different from the predicted ones which can be a priori stored in soft_suit. This is typical for performing of actions initiated by c-granules.

C-granules are generated by an agent *ag* depending on the specific configurations of spatio-temporal portions of physical matter (called hunks [5]) related to the *ag*. It should be underlined that any typical active c-granule is a dynamically changing entity. It means that all components of c-granules (*i.e.*, soft_suits, link_suits and hard_suits) are usually subject to continuous changes.

Many advanced tasks, concerning complex systems may be classified as control tasks performed by agents aiming at achieving the high quality computational trajectories of c-granules relative to the considered quality measures over the trajectories. Here, new challenges are to develop strategies to control, predict, and bound the behavior of the system. We propose to investigate these challenges using the IGrC framework.

The reasoning, which aims at controlling the computational schemes from time-to-time, in order to achieve the required targets, is called an *adaptive judgement*. Adaptive judgment plays a crucial role in the assessment of what is currently important, and what is less important. Therefore, it constitutes the basis for the evaluation and improvement of interaction plans that are being implemented. In a sense, judgment [3,4,13,14,35] may be treated as an elaboration of the concept of rational reasoning (especially about the properties of computations in IGrC) due to the necessity of taking into account not only mechanisms of logical reasoning, but also mechanisms that influence decisions, which are being made. These mechanisms pertain, *e.g.*, to perception, emotions, instinct, habits, intuition, fast thinking [13], and experience. Thus, adaptive judgment is not only limited to deduction, induction, and abduction. A deeper understanding of the concept of adaptive judgment should be supported by psychology and phenomenology [16]. This reasoning deals with granules and computations over them. Due to the uncertainty the agents generally cannot predict exactly the results of actions (or plans). Moreover, the approximations of the complex vague concepts initiating actions (or plans) are drifting with time. Hence, adaptive strategies for inducing changes in approximations of concepts are needed. In particular, the adaptive judgement is very much needed in the efficiency management of interactive granular computations, carried out by agents, for risk assessment, risk treatment, and cost/benefit analysis.

Thanks to c-granules, it is possible to register both the results of sensory measurements and their hierarchical aggregations, which are performed to discover new c-granules. The hierarchical c-granules discovered in this manner may ensure a deeper understanding of a perceived situation (see [1]). The statement above about the aggregation of c-granules (representing hierarchical aggregations of the results of sensory measures) refers to the main, according to Valiant[1], AI challenge, which is the characterization of "computational building blocks" [34] for perception.

The key role in the proposed approach is played by the techniques of adaptive and interactive discovery of c-granules (through interactions with the environment) and their further use. It turns out that in order to perform computations on c-granules, *ecorithms*, as understood by Valiant [33], should be used instead of classical algorithms. Apart from the analogy to Valiant's ecorithms, the IGrC-based proposed algorithms display a number of other features, which correspond to the motivations of scientific research in other domains (*e.g.*, learning systems,

[1] http://www.seas.harvard.edu/directory/valiant.

CAS, soft-computing, multi-agent systems, natural computations). The Wistech IGrC model is also related to the very foundations of AI, in particular, to the understanding of the essence of machine learning.

In particular, in Complex Systems Engineering (CSE) [7], the design and implementation of a complex project may be seen as the process of discovering, learning, processing (including communicating), and developing concepts (represented as c-granules), which are necessary to deal with a given project. The key to success in managing any complex project is a skillful approximation of complex vague concepts, represented by c-granules, and a skillful use of c-granules by those, who are in charge of a given project. Such approximations are responsible, *e.g.*, for initiation of actions performed by agents [7].

It is worth mentioning that the proposed model of interactive computations on c-granules differs from the Turing model.

The main ideas of IGrC have their roots in the research on rough sets, initiated by Pawlak [20–22,31]. At this point, we are particularly referring to Pawlak's approach to such concepts as: concept approximations, information systems, decision tables (as they are understood in a rough set theory) and Boolean reasoning about vague concepts.

The presented approach to the Wistech IGrC model is an extension of the joint research with Jankowski [8–12,19,26–28,30] The approach is a step towards realization of the Wisdom Technology (WisTech) program [7–10,29] in combination with IGrC, and is developed over years of experiences, based on the work on different real-life projects. The discussed model is called the Wistech IGrC model.

The results of the research presented in this paper may also be analyzed from the point of view of their potential contribution to advancements in dynamically developing scientific disciplines, such as CSE [18,25], granular computational models [23], interactive computational models [2], models of natural computing [24], models of learning systems [33], or models of computations performed by multi-agent systems [15,32].

Other issues such as communication language evolution and risk management in interactive computations will be discussed in more detail in our next papers (see also [7]).

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References

1. Bazan, J.: Hierarchical classifiers for complex spatio-temporal concepts. In: Peters, J.F., Skowron, A., Rybiński, H. (eds.) Transactions on Rough Sets IX. LNCS, vol. 5390, pp. 474–750. Springer, Heidelberg (2008)
2. Goldin, D., Smolka, S., Wegner, P. (eds.): Interactive Computation: The New Paradigm. Springer, Heidelberg (2006)

3. Grossi, D., Pigozzi, G.: Judgment Aggregation: A Primer, Synthesis Lectures on Artificial Intelligence and Machine Learning, vol. 27. Morgan & Claypool, Los Altos (2014)
4. Hager, P., Halliday, J.: Recovering Informal Learning Wisdom, Judgement and Community. Springer, Heidelberg (2006)
5. Heller, M.: The Ontology of Physical Objects. Four Dimensional Hunks of Matter. Cambridge Studies in Philosophy. Cambridge University Press, Cambridge (1990)
6. Holland, J.H.: Signals and Boundaries Building Blocks for Complex Adaptive Systems. The MIT Press, Cambridge (2014)
7. Jankowski, A.: Complex Systems Engineering: Wisdom for Saving Billions Based on Interactive Granular Computing. Springer, Heidelberg (2016, in preparation)
8. Jankowski, A., Skowron, A.: A wistech paradigm for intelligent systems. In: Peters, J.F., Skowron, A., Düntsch, I., Grzymała-Busse, J.W., Orłowska, E., Polkowski, L. (eds.) Transactions on Rough Sets VI. LNCS, vol. 4374, pp. 94–132. Springer, Heidelberg (2007)
9. Jankowski, A., Skowron, A.: Logic for artificial intelligence: Rasiowa - Pawlak school perspective. In: Ehrenfeucht, A., Marek, V.M., Srebrny, M. (eds.) Andrzej Mostowski and Foundational Studies, pp. 106–143. IOS Press, Amsterdam (2008)
10. Jankowski, A., Skowron, A.: Wisdom technology: a rough-granular approach. In: Marciniak, M., Mykowiecka, A. (eds.) Aspects of Natural Language Processing. LNCS, vol. 5070, pp. 3–41. Springer, Heidelberg (2009)
11. Jankowski, A., Skowron, A., Dutta, S.: Toward problem solving support based on big data and domain knowledge: interactive granular computing and adaptive judgement. In: Japkowicz, N., Stefanowski, J. (eds.) Big Data Analysis: New Algorithms for a New Society. Series in Big Data, vol. 16, pp. 49–90. Springer, Heidelberg (2016)
12. Jankowski, A., Skowron, A., Swiniarski, R.: Interactive complex granules. Fundamenta Informaticae **133**(2–3), 181–196 (2014)
13. Kahneman, D.: Thinking, Fast and Slow. Farrar, Straus and Giroux, New York (2011)
14. Koehler, D.J., Harvey, N.: Blackwell Handbook of Judgment and Decision Making. Blackwell Publishing, Oxford (2004)
15. Liu, J.: Autonomous Agents and Multi-agent Systems: Explorations in Learning, Self-organization and Adaptive Computation. World Scientific Publishing, Singapore (2001)
16. Martin, W.M. (ed.): Theories of Judgment. Psychology, Logic, Phenomenology. Cambridge University Press, New York (2006)
17. Meia, S., Zarrabi, N., Lees, M., Sloot, P.M.: Complex agent networks: an emerging approach for modeling complex systems. Appl. Soft Comput. **37**, 311–321 (2015)
18. National Aeronautics and Space Administration: NASA Systems Engineering Handbook. NASA Headquarters, Washington, D.C (2007)
19. Nguyen, H.S., Jankowski, A., Skowron, A., Stepaniuk, J., Szczuka, M.: Discovery of process models from data and domain knowledge: a rough-granular approach. In: Yao, J.T. (ed.) Novel Developments in Granular Computing: Applications for Advanced Human Reasoning and Soft Computation, pp. 16–47. IGI Global, Hershey (2010)
20. Pawlak, Z.: Rough sets. Int. J. Comput. Inf. Sci. **11**, 341–356 (1982)
21. Pawlak, Z.: Systemy Informacyjne. Podstawy Teoretyczne (Information Systems. Theoretical Foundations). Wydawnictwa Naukowo-Techniczne (1983). http://bcpw.bg.pw.edu.pl/dlibra/docmetadata?id=2327

22. Pawlak, Z.: Rough Sets: Theoretical Aspects of Reasoning About Data, System Theory, Knowledge Engineering and Problem Solving, vol. 9. Kluwer Academic Publishers, Dordrecht (1991)
23. Pedrycz, W., Skowron, S., Kreinovich, V. (eds.): Handbook of Granular Computing. Wiley, Hoboken (2008)
24. Rozenberg, G., Bäck, T., Kok, J. (eds.): Handbook of Natural Computing. Springer, Heidelberg (2012)
25. Sage, A., Rouse, W.: Handbook of Systems Engineering and Management. Wiley-Interscience, Hoboken (2014)
26. Skowron, A., Jankowski, A.: Interactive computations: toward risk management in interactive intelligent systems. Nat. Comput. doi:10.1007/s11047-015-9486-5
27. Skowron, A., Jankowski, A., Dutta, S.: Interactive granular computing. Granul. Comput. **1**, 95–113 (2016)
28. Skowron, A., Jankowski, A., Swiniarski, R.: 30 years of rough sets and future perspectives. In: Ciucci, D., Inuiguchi, M., Yao, Y., Ślęzak, D., Wang, G. (eds.) RSFDGrC 2013. LNCS, vol. 8170, pp. 1–10. Springer, Heidelberg (2013)
29. Skowron, A., Jankowski, A., Wasilewski, P.: Risk management and interactive computational systems. J. Adv. Math. Appl. **1**, 61–73 (2012)
30. Skowron, A., Stepaniuk, J., Jankowski, A., Bazan, J.G., Swiniarski, R.: Rough set based reasoning about changes. Fundamenta Informaticae **119**(3–4), 421–437 (2012)
31. Skowron, A., Suraj, Z. (eds.): Rough Sets and Intelligent Systems. Professor Zdzisław Pawlak in Memoriam. Series Intelligent Systems Reference Library, vol. 42-43. Springer, Heidelberg (2013)
32. Sun, R. (ed.): Cognition and Multi-Agent Interaction. From Cognitive Modeling to Social Simulation. Cambridge University Press, Cambridge (2006)
33. Valiant, L.: Probably Approximately Correct. Nature's Algorithms for Learning and Prospering in a Complex World. Basic Books, A Member of the Perseus Books Group, New York (2013)
34. Valiant, L.: Research interests. http://people.seas.harvard.edu/~valiant/researchinterests.htm
35. van Dalen, D. (ed.): Brouwer's Cambridge Lectures on Intuitionism (1951). Cambridge University Press, Cambridge (1981)
36. Yang, A., Shan, Y.: Intelligent Complex Adaptive Systems. IGI Global, Hershey (2008)